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Effect of Annealing Temperature on Magnetic and Structural Properties of ALNICO-5 Alloy

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Abstract. The crystal structure of an Alnico-5 Alloy during different annealing temperature up to 1050 °C for 1 hour has been monitored by measuring the magnetic hysteresis loop. X-ray diffraction and vibrating sample magnetometer (VSM) were used to characterize the phase composition and magnetic properties. The results found that, the effect of the annealing degree is the major parameter on particle size, phase transition and magnetic properties. The results also showed that grain size decreased with the increasing temperature from 18.3 nm at room temperature to 12.2 nm at 950°C. The maximum coercive force (He) with residual magnetization (Br) also increased with increasing temperatures above RT. The oxidation of the alloy with new crystalline phase leads to change the magnetic and structure properties at 1050 °C were found. A good correlation has been established between the structure and magnetic properties.

Keywords: Alinco Alloys ,Magnetic properties , Hysteresis loop

1. Introduction

Alnico alloys are very important group of Permanent magnetic alloys which are used in wide range of electrical and electronic devices [1,2]. Such as mini-transducer for Mossbuar [3],Gint Magneto Resistance(GMR)[4] and recently as Alnico bonded magnet [5]

They contain Fe, Co, Ni and Al with minor addition of Cu and Ti [6, 7]. These alloys have attracted considerable work, both theoretical and experimental because of their magnetic properties, good corrosion resistance, heat treatment, high Curie temperature and the highest saturation rnagnetization [8]. More recently the structure of some titanium and niobium adding to the Alnico composition has been examined in an attempt to find the reason for their high coercivity and saturation magnetization [9, 10].

These Alnico alloys can be divided into more than nine types, depending on atypical nominal composition and improvement in magnetic properties during a suitable method of preparing [6, 8].

Most of the studies and all attention in the literature have been focused on magnetic, electrical and mechanical properties but the understanding the effect of heat treatment on magnetic and structural properties of Alnico-5 is still insufficient. In the present work the correlation between the variations of the magnetic and structure properties at different annealing temperature has been studied.

2. Experimental Work

Laboratory ingots (I Kg) of Alnico-5 magnetic alloy was prepares as bulk using high purity materials (≥99.97%) of Co, Ni, Cu, Al and Aramco Iron. The materials were melted in high frequency induction furnace using crucible of pure alumina. The aluminium was added during the final stages of melting to prevent excessive losses of this element.

The alloy was then given thermo magnetic treatment at 1200 °C then slow cooling in a magnetic field of 3500 Oe for 30 minutes, followed by aging at 600°C for 2 hr.

Compositional analysis of the bulk specimens were determined by Atomic absorption flame emission (ABE) type (Shimad 24, AA-670) and compared with the Energy Dispersive X-ray analysis (EDSX) type (Quanta 200, FEI) .

Samples were annealed at various temperatures 700, 950 and 1050 °C for 1 hr and then slow cooling by using Carbolite furnace . The temperature during the annealing was stabilized to better than ±2 ^{0}C.

The samples were characterized structurally for different annealing temperatures using X-ray diffraction

Co K_α λ= 0.179 nm radiations on a Philips diffractometer type 1729.

The average grine size was measured using Scherrer formula which is connected to the XRD line width [11].

Magnetic measurements were obtained by using vibrating sample magnetometer (VSM) and portable susceptibility system. The coercive force H_e , remanence magnetization B_r have been measured from (B-H) hysteresis loops at different annealing temperature.

The thermal stability were also studied by using differential thermal analysis (DT A) type (Netzsch, Sta, 409) at heating rate 5 °C/min in continuous heating experiment.

3. Results and Discussion

Table (1) shows the chemical compositions of the prepared Alnico-5 alloys. The composition of the alloys presented by different methods give similar values, showing that atypical close to the standard values [11].

Table 1. Chemical compositions of the experimentally studied Alnico-5 alloy

Method	Chemical Composition, % wt				
	Co	Ni	Al	Cu	Fe
EDSX (Ingot)	23.21	14.60	8.74	3.63	Rem
ABE (Ingot)	23.81	14.13	8.60	2.98	Rem
Standard Values (Z)	24	14.5	8.5	3	Rem

Atypical energy spectrum for this alloy (EDSX) is shown in figure (1). Analysis of these spectra has measured after background subtraction and separation of the overlapping peaks.

Figure (2) shows the X-ray diffraction pattern for Alinco-5 alloys at different annealing temperatures, which approved a cubic structure.

It is clear from the figure (2) that the diffraction peak at 2θ= 51.08 becomes narrower as the annealing temperature increases from RT to 950 C^0 , this indicates that the crystallized structure dominated bellow 950°C, due to BCC structure. This has also been characterized as strongly ferromagnetic alloys by high iron or cobalt content (Fe-Co) phase.

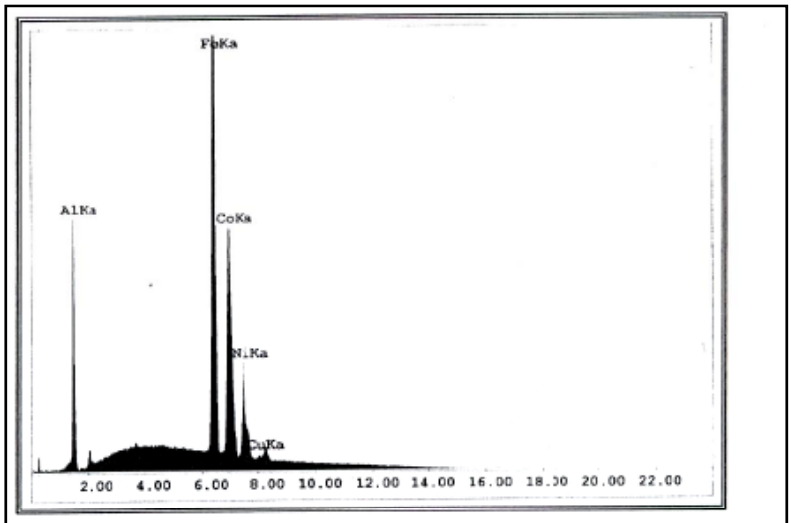
A considerable difference pattern with small split was found when the alloy is annealed at 1050 °C, which indicated that Oxidation or a significant new structure change, probably a weakly ferromagnetic (Ni-Al) phase which is clearly shown in figure (2).

The structure transformation a1050 C^0 was also detected very clear from thermal analysis (DT A) as shown in figure (3).

The hysteresis loops (H-B) at different annealing temperature are given in figure (4).

Increase in magnetic properties with increasing annealing temperature was observed.

The coercivity force H_c and remanence magnetization B_r appeared to change more significantly and shift sign above RT, which is related to an improvement of soft magnetic behavior.



Element	Wt %	At %	K-Ration	Z	A	F
Alk	8.74	15.91	0.0422	1.0967	0.4400	1.0002
Fek	49.82	45.57	0.5062	0.9928	0.9981	1.0254
Cok	23.21	20.56	0.2268	0.9725	1.0001	1.0047
Nik	14.60	12.98	0.1422	1.0074	0.9670	1.0000
Cuk	3.63	2.98	0.0335	0.9591	0.9622	1.0000
Total	100.00	100.00				

Element	Net Inte.	Bkgd Inte.	Inte. Error	P/ B
Alk	102.21	11.70	0.86	8.73
Fek	219.55	6.75	0.54	32.51
Cok	78.31	5.73	0.94	13.66
Nik	38.32	5.15	1.42	7.45
Cuk	6.85	4.26	4.47	1[.61

Fig. 1: ESAX for a Alnico-5 Alloy showing elemental spectral peaks

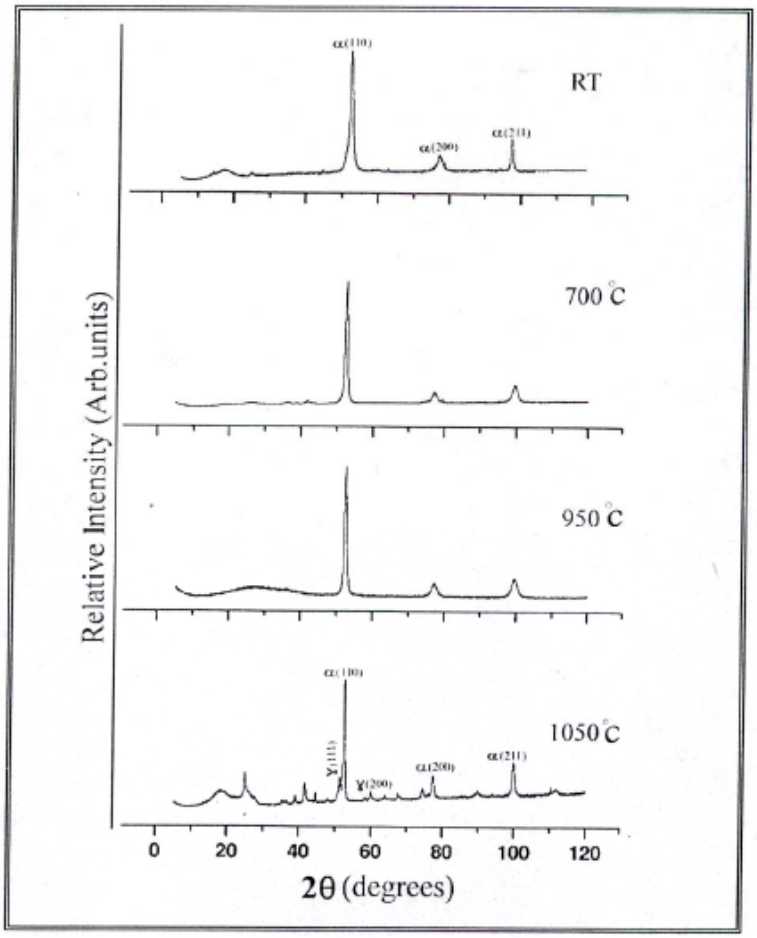


Fig. 2: X-ray diffraction of Alinco-5 scetion

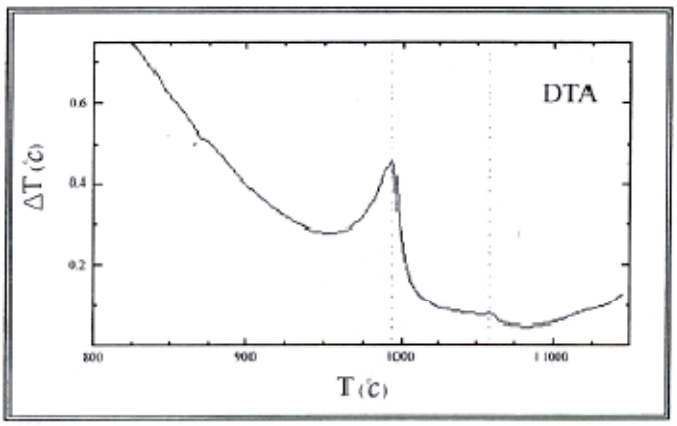


Fig. 3: DTA measurement of Alnico-5 Alloy

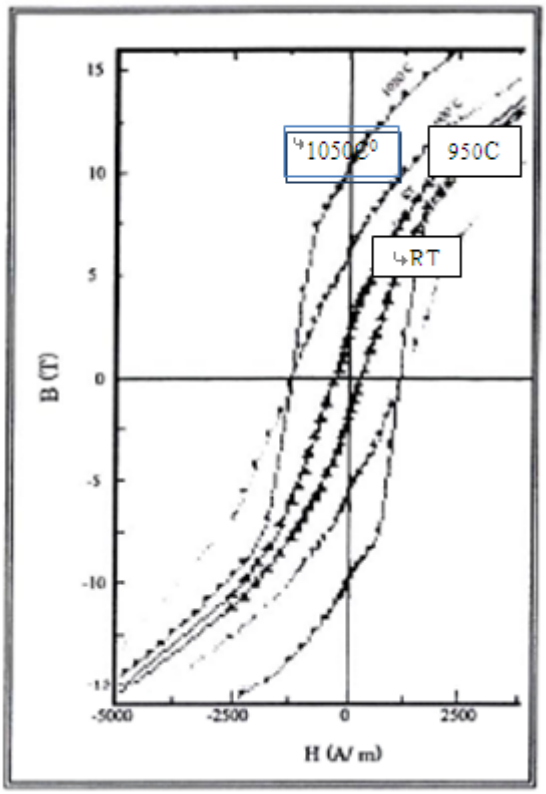


Fig. 4: B-H hysteresis loops of Alnico-5 Alloy at different annealing temperatures

A remarkable increase of H_c at 1050 °C was observed but there is no significant effect on B_r at this annealing temperature. This could be due to the phase transformation as mentioned earlier with the XRD results.

Finally, the changeable of these magnetic quantities can be explained as related to the degree of crystallization which can be affected by the average grain size. The grain sizes calculated from Scherer equation was found to decrease from 18.30 nm at RT to 12.20 nm at 950°C, which can play an important role to control the mobility of domain walls of magnetic structure. Therefore, leading to conclusion that the magnetic properties must contain small particle size in order to keep a maximum of corecivity and remanence values.

4. Conclusions

Alnico-5 alloy was prepared using a high purity materials in high frequency induction furnace Changes in magnetic and structural properties were examined under the influence of different annealing temperatures

for **1** hr. From the hysteresis loops, the coercivity force and remanence magnetization parameters were found to increase up to 950°C. A remarkable increase of coercivity force at 1050 °C was observed but the remanence was found to be independent on temperature probably due to Oxidation or a new phase dominated. Similar results have also obtained by X-ray diffraction. Significant difference pattern was found after annealing at this degree. We investigated also the influence of grain size on the magnetic properties, and we found that the particle size strongly related with the magnetic properties.

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